X TROPHIC STATUS AND PERMISSIBLE LOADINGS

A. Introduction

The trophic status of a waterbody is a hybrid concept referring to the nutritive state (especially phosphorus) of a lake or pond, but is often described in terms of biological activity that occurs as a result of nutrient levels. Trophic state indices have been developed both on the use of a single parameter and on the use of several parameters.

Table X-1, reproduced in part from the EPA Clean Lakes Program Guidance Manual (1980), describes the lake water characteristics of the oligotrophic and eutrophic states. Mesotrophic conditions exist between the limits for eutrophy and oligotrophy.

Table X-1
Summary of Quantitative Definitions of Lake Trophic Status

Characteristics	Oligotrophic	Eutrophy
Total phosphorus (ug/L, winter)	≤ (10 to 15)	≥ (20 to 30)
Chlorophyll-a (ug/L, summer)	≤ (2 to 4)	≥ (6 to 10)
Secchi disk depth (m, summer)	≥ (3 to 5)	≤ (1.5 to 2)

This chapter will examine several trophic classification and permissible loading schemes.

B. Trophic Classification Schemes

1. State of New Hampshire Trophic Classification System

The classification system developed by the Biology Bureau of the New Hampshire Water Supply and Pollution Control Division (Table X-2) utilizes four parameters (Towne and Estabrook, 1981). Table X-3 lists, for Mendums Pond, the calculated value of each classified parameter for the 1979 and 1987 surveys and the 1988 study year, the trophic points received and the trophic status.

Table X-2

TROPHIC CLASSIFICATION SYSTEM FOR NEW HAMPSHIRE LAKES AND PONDS

	TROPHIC POINTS
1. Summer Bottom Dissolved Oxygen:	
a. D.O. $\geq$ 5mg/l	0
b. 2mg/l $\leq$ D.O. < 5mg/l & <30 foot depth	1
c. 2mg/l $\leq$ D.O. < 5mg/l & $\geq$30 foot depth	2
d. .5mg/l $\leq$ D.O. <2mg/l & <30 foot depth	3
e. .5mg/l $\leq$ D.O. <2mg/l & $\geq$30 foot depth	4
f. D.O. <.5mg/l & <30 foot depth	5
g. D.O. <.5mg/l & $\geq$30 foot depth	6
2. Summer Secchi Disk Transparency:	
a. > 24 feet	0
b. > 12 feet to 24 feet	1
c. > 6 feet to 12 feet	2
d. > 3 feet to 6 feet	3
e. > 1 foot to 3 feet	4
f. > .5 foot to 1 foot	5
g. $\leq$ .5 foot	6
3. Aquatic Vascular Plant Abundance:	
a. Sparse	0
b. Scattered	1
c. Common	2
d. Abundant	3
e. Very abundant	4
4. Summer Epilimnetic Chlorophyl *a* (mg/M^3):	
a. Chl *a* <5	0
b. 5 $\leq$ Chl *a* <10	1
c. 10 $\leq$ Chl *a* <20	3
d. Chl *a* $\geq$ 20	5

TROPHIC CLASSIFICATION	TROPHIC POINTS STRATIFIED	TROPHIC POINTS *UNSTRATIFIED
Oligotrophic	0-5	0-3
Mesotrophic	6-10	4-6
Eutrophic	11-21	7-15

*Unstratified lakes are not evaluated by the bottom dissolved oxygen criterion.

Table X-3

Trophic Classification of Mendums Pond

Trophic Classification - 1979 Survey

Parameter	Value		Trophic Points
Dissolved Oxygen	5.5 mg/L		0
Secchi Disk	3.0 m		2
Plant Abundance	Scattered		1
Chlorophyll-a	1.76 mg/m^3		0
		Total	3
Trophic Status			Oligotrophic

Trophic Classification - 1987 Survey

Parameter	Value	Trophic Points	Trophic Points (Revised)
Dissolved Oxygen	7.3 mg/L	0	0
Secchi Disk	2.8 m	2	3
Plant Abundance	Scattered	1	1
Chlorophyll-a	4.54 mg/m^3	0	1
	Total	3	5
Trophic Status		Oligotrophic	Oligotrophic

Revised Trophic Classification

Method - 1988 Study Year

Parameter	Value		Trophic Points
Dissolved Oxygen	*5.1 mg/L		0
Secchi Disk	*3.6 m		2
Plant Abundance	Scattered		1
Chlorophyll-a	*3.0 mg/m^3		0
		Total	3
Trophic Status			Oligotrophic

*Mean value

Mendums Pond received a total of 3 trophic points in 1979 and in 1987, classifying it as oligotrophic. It is encouraging to see that the lake quality did not decline over that period of time.

The system used to trophically classify New Hampshire lakes and ponds was revised in 1989 (Table X-4). The purpose of the revision was to provide for equal points under each attribute and to reduce the impact of the bottom dissolved oxygen criterion. Unlike the previous system, the extent of oxygen depletion is evaluated in the new system.

The revised classification system was applied to the 1987 survey data to compare the two systems. In both instances Mendums Pond was classified as oligotrophic. The data from the 1988 summer sampling period was compiled to determine trophic status using the revised classification system and incorporating many sampling dates. Once again it fell into the oligotrophic status.

Table X-4

Trophic Classification System for New Hampshire Lakes and Ponds (Revised 1989)

TROPHIC POINTS

1. Summer Bottom Dissolved Oxygen (mg/L):

a.	D.O. >4 mg/L	0
b.	D.O. = 1 to 4 mg/L & hypo. vol. ≤ 10% lake vol	1
c.	D.O. = 1 to 4 mg/L & hypo. vol. > 10% lake vol	2
d.	D.O. <1 mg/L in <1/3 hypo. vol. & hypo. vol. ≤ 10% lake vol	3
e.	D.O. <1 mg/L in ≥1/3 hypo. vol. & hypo. vol. ≤ 10% lake vol	4
f.	D.O. <1 mg/L in <1/3 hypo. vol. & hypo. vol. > 10% lake vol	5
g.	D.O. <1 mg/L in ≥1/3 hypo. vol. & hypo. vol. > 10% lake vol	6

2. Summer Secchi Disk Transparency (M):

a.	>7m	0
b.	>5m - 7m	1
c.	>3m - 5m	2
d.	>2m - 3m	3
e.	>1m - 2m	4
f.	>.5m -1m	5
g.	≤.5m	6

3. Summer Vascular Aquatic Plant Abundance:

a.	Sparse	0
b.	Scattered	1
c.	Scattered/Common	2
d.	Common	3
e.	Common/Abundant	4
f.	Abundant	5
g.	Very Abundant	6

4. Summer Epilimnetic Chlorophyll a (mg/m^3):

a.	< 4	0
b.	4 - < 8	1
c.	8 - < 12	2
d.	12 - < 18	3
e.	18 - < 24	4
f.	24 - < 32	5
g.	≥32	6

TROPHIC CLASSIFICATION	TROPHIC POINTS STRATIFIED	TROPHIC POINTS *UNSTRATIFIED
Oligotrophic	0 - 6	0 - 4
Mesotrophic	7 - 12	5 - 9
Eutrophic	13 - 24	10 - 18

*Lakes with no hypolimnion are not evaluated by the bottom dissolved oxygen criterion.

2. Carlson's Trophic State Index

Carlson's (1977) TSI system is based upon Secchi depth as a means of characterizing algal biomass. This parameter, in the absence of turbidity and colored materials in water, is a direct measure of "plankton-algal manifested eutrophication processes" in natural waters. Its range of values can easily be transformed into a convenient scale. Further, by using empirically derived relationships between Secchi depth and both phosphorus and chlorophyll-a concentration, Carlson has derived equations to estimate the same index value from these two parameters as well as from Secchi depth. Carlson's trophic index is basically a linear transformation of Secchi depth, such that each major unit in his scale has half the value of the next lowest unit. Conversely, for total phosphorus and chlorophyll-a, each major unit in his scale has larger values for the next higher unit. The computational form of the equations for his trophic scheme is as follows:

$$TSI_{(SD)}=10\ (6-\log_2 SD),$$

$$TSI_{(TP)}=10\ (6-\log_2 48\ \frac{1}{TP}),\ \text{and}$$

$$TSI_{(Chl\underline{a})}=10\ (6-\log_2 7.7\ \frac{1}{Chl\underline{a}\ 0.68})$$

where:

SD = Secchi depth (m)

TP = Total phosphorus concentration (mg/M^3) and

Chl-a = Chlorophyll-a concentration (mg/M^3)

According to Carlson (1977), this index system has the advantages of easily obtained data, simplicity absolute TSI values, valid relationships, retrieval of data from the index, and can be grasped by the layman in much the same manner as the Richter earthquake scale. The TSI incorporates most lakes in a scale of 0 to 100 as Figure X-1 demonstrates. Each major division (10, 20, 30, etc.) represent a doubling of algal biomass.

Results of the Carlson TSI were obtained by substituting summer mean Secchi depth, chlorophyll-a, and phosphorus values from Mendums Pond into the equations to compute the TSI. Table X-5 shows the mean summer values, the TSI number and the classification for each measured parameter. The chlorophyll-a values observed at Mendums Pond reflect low to moderate concentrations that would be observed in an oligotrophic/mesotrophic lake or pond. Median Secchi

Carlson's Trophic State Index

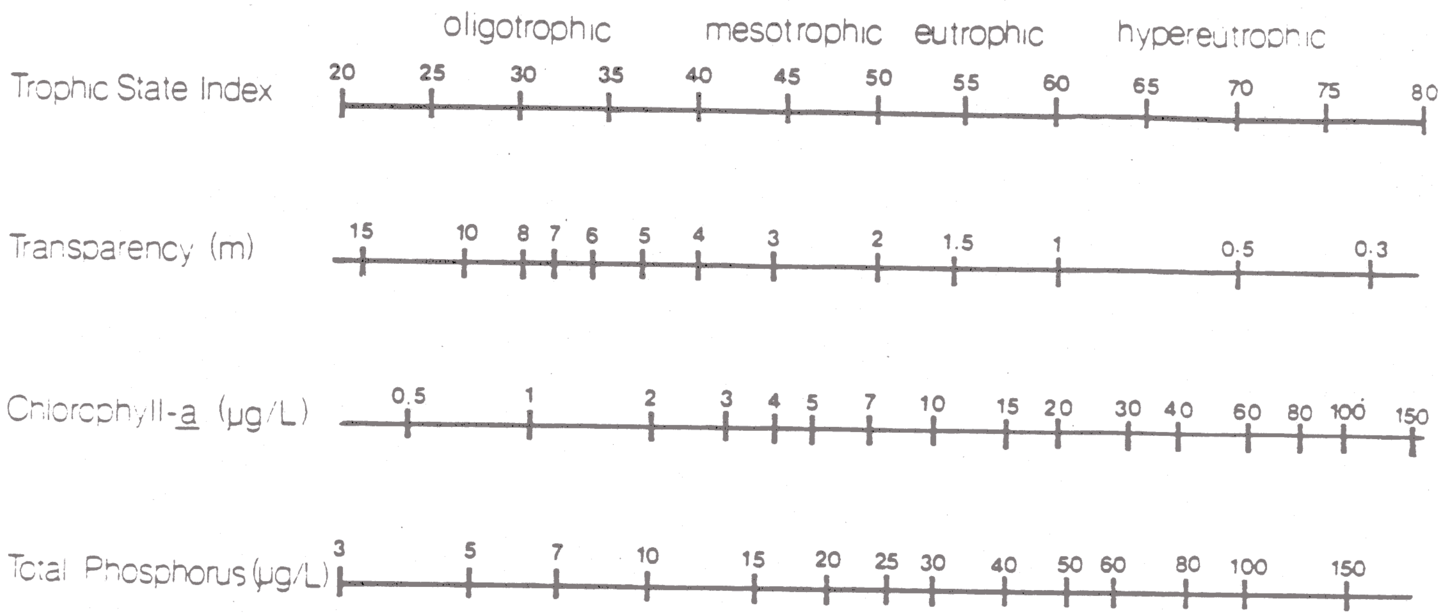


Figure X-1. Carlson's Trophic State Index Scale.

disk observations were representative of borderline mesotrophic/oligotrophic conditions. An examination of mean summer in-lake phosphorus concentrations, for the epilimnion/hypolimnion, showed a Carlson ranking of oligotrophic for the epilimnion, and oligotrophic for the hypolimnion.

Table X-5
Carlson Trophic Classification
for Mendums Pond

Parameter	Mean Summer Value		Trophic Points	Classification
Chlorophyll-a (mg/m^3)		3.0	41	Mesotrophic/ Oligotrophic
Secchi Disk (m)		3.6	42	Mesotrophic/ Oligotrophic
Phosphorus (ug/L)	Epi.	9	24	Oligotrophic/
	Hypo.	9	24	Oligotrophic

3. Dillon & Rigler Permissible Loading Model

Mathematical models can also be useful both in diagnosing lake problems and evaluating potential solutions. They represent in quantitative terms the cause-effect relationships that determine lake quality. In some cases, the determination of the trophic state of a lake involves a comparison of actual phosphorus loading to the lake with a maximum permissible loading that the lake can tolerate before excessive weed and algae growth occurs and transparency diminishes. The trophic model developed by Dillon/Rigler (1975) has been widely utilized and well documented by researchers. Its application classifies a lake as oligotrophic, mesotrophic or eutrophic by comparing calculated actual loadings with permissible annual loadings. The tolerance of the lake to phosphorus loading is predicted as function of two morphological parameters, mean depth (z) and water retention time (T), which have been proven by several researchers to be the primary determinants of loading permissibility. Additionally, the model considers the phosphorus retention in the lake sediments. The retention coefficient (R) may be empirically calculated from morphological data or may be derived from a definitive phosphorus budget.

Table X-6 shows the qualitative relationship between the model input parameters and phosphorus loading tolerance.

Table X-6

Dillon/Rigler Permissible Loading Tolerance

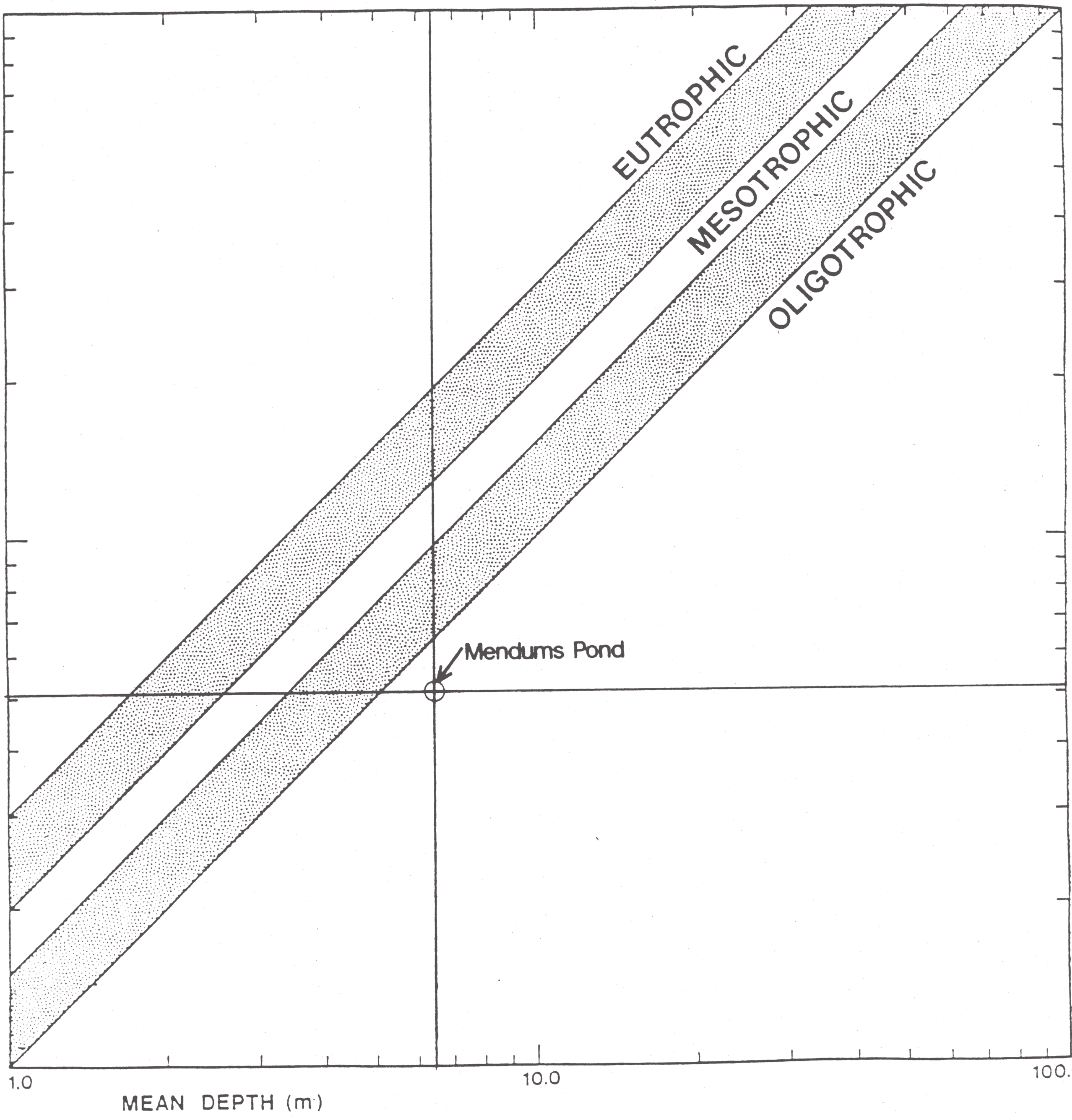
High Phosphorus Loading Tolerance	Low Phosphorus Loading Tolerance
*Large mean water depth	*Small mean water depth
*Rapid flushing rate	*Slow flushing rate
*High sediment retention	*Low sediment retention

Thus, existing trophic status is set by existing values for these parameters and annual phosphorus loading. Similarly, historical trophic status can be determined from estimates of previous phosphorus loading. The degree of trophic state improvement, which would result from the implementation of watershed and in-lake management strategies, can be gauged from predicted changes of loading and morphology. Table X-7 presents the Dillon/Rigler trophic status calculations for Mendums Pond. Figure X-2 is a graphical representation of the Dillon/Rigler model showing trophic zones, plotted on axes of mean depth and areal loading (Table X-7) with the data point for the Mendums Pond study year.

TABLE X-7

Dillon/Rigler Trophic Status Calculations

Parameter	Calculation
Lake area (m^2)	1,033,900
Mean z (m)	6.4
Total loading (Kg)	356.5 Kg
Flushing rate (yr^{-1})	1.43
Water Retention Time(yr) T	0.70
P coefficient R	0.79
Total areal loading ($g/m^2/yr$) L	0.345
LT (1-R) (g/m^2)	0.051



L = AREAL PHOSPHORUS LOADING ($g/m^2/yr$)
R = PHOSPHORUS RETENTION COEFFICIENT (DIMENSIONLESS)
T = HYDRAULIC RETENTION TIME (yr)

FIGURE X-2. DILLON/RIGLER TROPHIC STATUS FOR MENDUMS POND, BARRINGTON, NH

The solution of the Dillon/Rigler equation for Mendums Pond data (unaltered morphology) shows the existing oligotrophic/mesotrophic boundary to exist between 447 and 682 $kgPyr^{-1}$ and the mesotrophic/eutrophic boundary to exist between 950 and 1385 $kgPyr^{-1}$. These boundaries for loadings are based on a mean depth (z) of 6.4 m, a water retention time (T) of 0.70 yr and a phosphorus retention coefficient (R), derived from the phosphorus budget, of 0.79. The actual budgeted phosphorus loading for the study year at Mendums Pond was 357 $kgPyr^{-1}$, which classifies the lake as oligotrophic. The model predicted that Mendums Pond received 359 $kgPyr^{-1}$. The Dillon/Rigler model demonstrates that an increased load of 88 $kgPyr^{-1}$ would decrease the lake quality enough to place Mendums at the oligotrophic/mesotrophic borderline. It would take an increase of 325 $kgPyr^{-1}$ to place Mendums Pond into the mesotrophic lake classification.

The Dillon/Rigler model also predicts in-lake phosphorus concentration. Utilizing the Dillon/Rigler equation $P=Lp/qs(1-R)$, the calculated predicted in-lake phosphorus concentration for Mendums Pond was 0.008 mg/L. This predicted value compares very favorably with an actual three year mean epilimnetic phosphorus concentration of 0.010 mg/L. The actual mean epilimnetic phosphorus concentration was calculated from three years of data collected by the Biology Bureau during the 1987 through 1989 sample years.

4 Vollenweider Phosphorus Loading and Surface Overflow Rate Relationship

The Vollenweider model is based on a five year study involving the examination of phosphorus load and response characteristics for about 200 waterbodies in 22 countries in Western Europe, North America, Japan and Australia. Vollenweider, working on the Organization for Economic Cooperation and Development (OECD) Eutrophication Study, developed a model describing the relationship of phosphorus load and the relative general acceptability of the water for recreational use (Vollenweider, 1975). Vollenweider found that when the annual phosphorus load to a lake is plotted as a function of the quotient of the mean depth and hydraulic residence time, lakes which were eutrophic tended to cluster in one area and oligotrophic lakes in another (Figure X-3, from Flanders, 1986).

Vollenweider developed a statistical relationship between areal annual phosphorus loading to a lake normalized by mean depth (z) and hydraulic residence time (T), to predict phosphorus lake concentration. Table X-8 summarizes the Vollenweider model parameters for the Mendums Pond sample year.

OECD DATA / VOLLENWEIDER PLOT

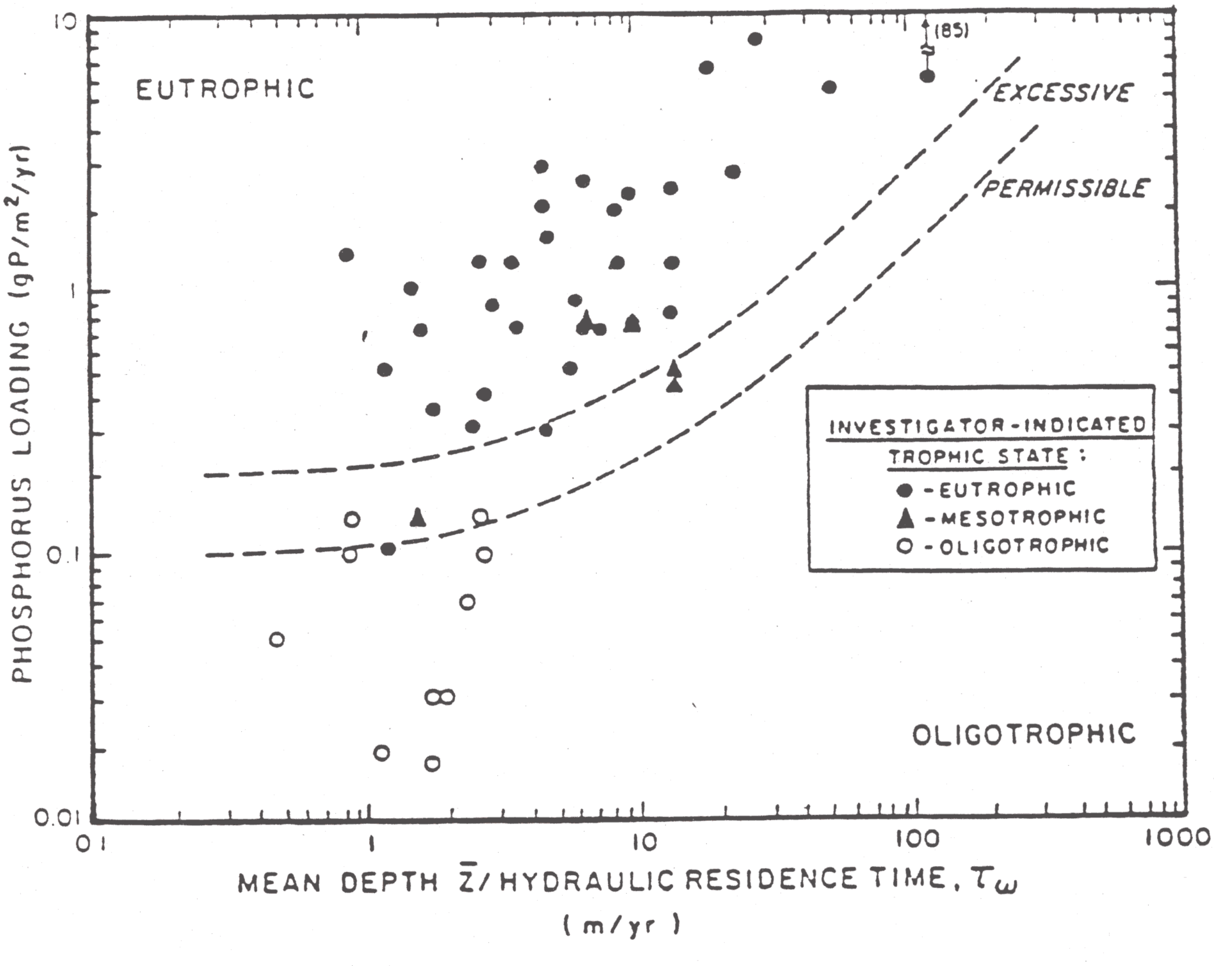


Figure X-3. OECD Data and the Vollenweider Plot.

TABLE X-8

Vollenweider Phosphorus Concentration Prediction

Parameter	Equation	Mendums Pond
1. Hydraulic residence time T	T=V/Q	0.70
2. Surface overflow rate (qs)	qs=z/T	9.14
3. Areal phosphorus	P load/lake surface area	0.345
4. Phosphorus concentration prediction	(Lp/qs) [1/(1+ z/qs)]	0.020

Thus, based on the physical constraints that control water volume, the hydraulic residence time in the lake, and mean lake depth, combined with phosphorus loading, the Vollenweider model predicts the existing in-lake phosphorus concentration to be 0.020 mg/L in Mendums Pond. An examination of actual mean epilimnetic in-lake phosphorus concentrations during the 1987-1989 study period, revealed that the actual concentration of 0.010 mg/L compared poorly with the in-lake concentration predicted by the Vollenweider model.

Figure X-4 graphically portrays the measured loading rates for Mendums Pond and compares the lake with other studied lakes in New Hampshire. Based on the permissible and excessive loading curves, it can be seen that Mendums Pond lies in the mesotrophic zone between the permissible and excessive loading ranges.

C. Trophic Classification Summary

A summary of the four classification schemes utilized in this study (Table X-9) shows that the New Hampshire Lake classification system classifies Mendums Pond as oligotrophic. The Dillon/Rigler model and Vollenweider Phosphorus Loading model classifies Mendums Pond as oligotrophic and mesotrophic respectively. The Carlson Trophic Status Index defines a trophic class for several parameters. Secchi disk transparency measurements in Mendums Pond and chlorophyll-a concentration fell into the mesotrophic/oligotrophic range, while phosphorus measurements were in the oligotrophic range.

On a permissible loading basis, the Dillon/Rigler model demonstrates that it would take an increased load of 88 $kgPyr^{-1}$ to decrease the lake quality enough to reflect characteristics of borderline mesotrophic/oligotrophic conditions.

D. Predicting the Capacity of Mendums Pond for Development

New Hampshire has experienced significant growth and development in the last two decades and is likely to continue to see such growth into the 1990's. This growth has greatly increased pressures on one of the very features that has attracted people to the state -- the lakes. While new development, both year-round and seasonal, and conversion/expansion of existing development allow more people to enjoy these resources, it also can threaten the quality of a lake environment.

VOLLENWEIDER PHOSPHORUS LOADING AND SURFACE OVERFLOW RATE RELATIONSHIP

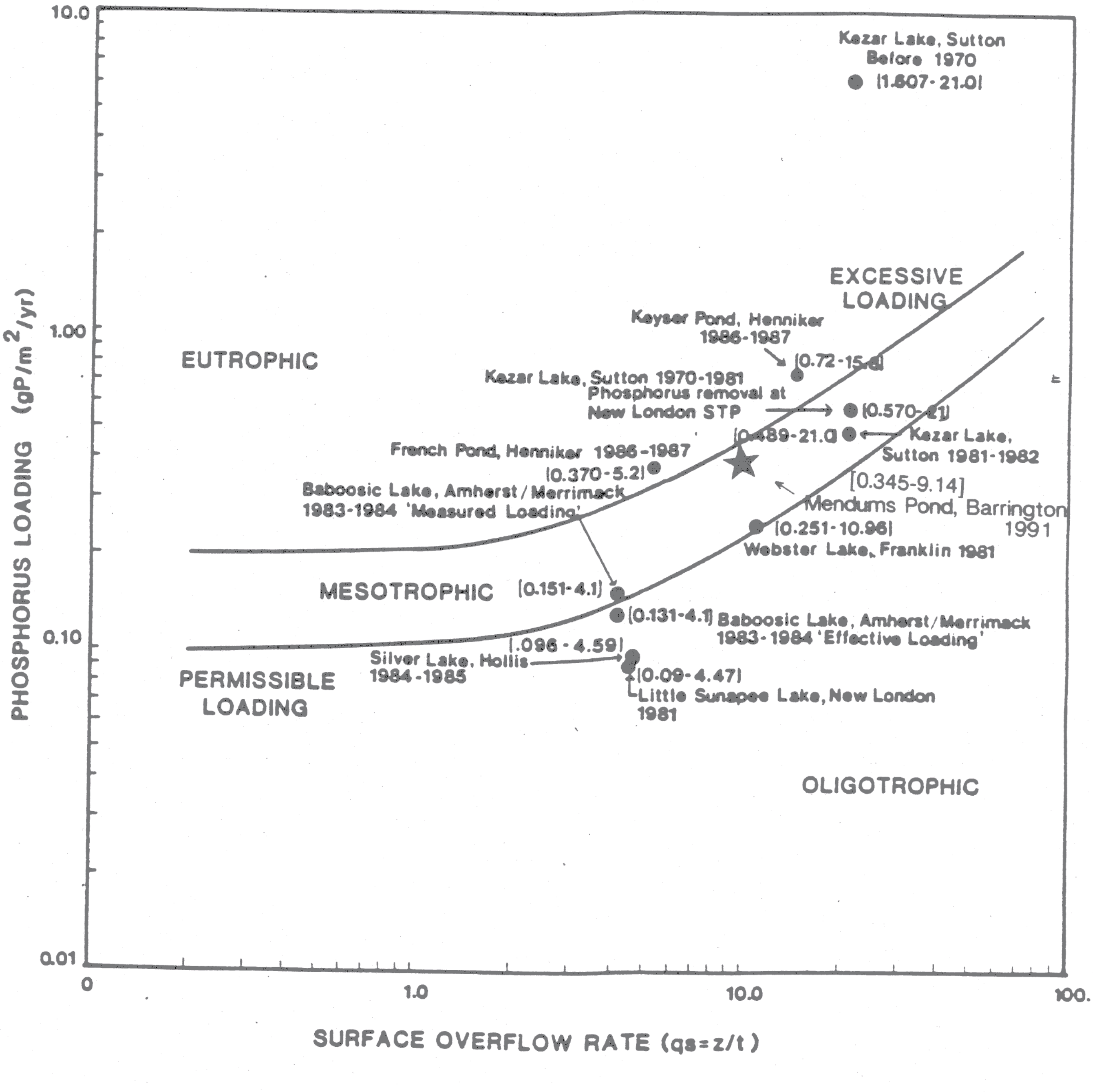


Figure X-4. Vollenweider Phosphorus Loading and Surface Overflow Rate Relationship.

Table X-9

Trophic Classification Summary

Classification Model	Trophic Classification Mendums Pond
1. New Hampshire Lake Classification	Oligotrophic
2. Carlson's TSI	
Chlorophyll-a	Mesotrophic/Oligotrophic
Secchi Disk	Mesotrophic/Oligotrophic
Phosphorus (Epilimnion)	Oligotrophic
Phosphorus (Hypolimnion)	Oligotrophic
3. Dillon/Rigler	Oligotrophic
4. Vollenweider	Mesotrophic

A predictive computer model has been utilized to aid in quantifying the environmental impacts of development on a lake. This model, which measures the phosphorus loading to a lake resulting from the surrounding development, predicts the capacity of the lake for seasonal and/or permanent development that will not threaten existing lake quality. Utilizing available data on the particular lake of interest and relying on several conservative assumptions about phosphorus impacts from certain kinds of development, the model presents the results in the form of a maximum number of allowable units of development around the lake. This number is intended as a guide for local officials in evaluating the impacts of proposed development on lakes.

Phosphorus (P) is the nutrient most frequently controlling lake productivity and, therefore, trophic status in New Hampshire lakes. Therefore, predictions concerning the impact of development on the phosphorus concentration of a lake, and subsequently on parameters describing the trophic state, are central to a predictive management scheme. From the geology and land use considerations of a lake's drainage basin, it is possible to estimate the total phosphorus exported or washed out per unit area of watershed. When combined with the drainage area, this provides an estimate of the total phosphorus supplied to the lake from the land. The addition of phosphorus input from direct lake precipitation determines the natural phosphorus load to the lake. Existing development--both year-round and seasonal--is then measured (tax maps or field counts with the assistance of local officials), and the phosphorus loading from artificial sources is calculated with the assistance of certain coefficients and conservative assumptions. The total P loading, natural plus artificial, may then be combined with the lake morphometry (general physical characteristics--size, depth, etc.) and water budget to predict a phosphorus concentration that is subsequently related to the average summer chlorophyll-a concentration. Chlorophyll-a is an indication of the planktonic algal biomass in the lake and is directly proportional to the phosphorus inputs. From the chlorophyll calculation one can calculate the lake clarity or Secchi disk transparency. Finally, the maximum permissible artificial loading that will not lower lake quality in terms of chlorophyll-a or water clarity can be estimated. This maximum is expressed as the maximum of allowable development units (i.e., number of cottages).

This model is designed to predict the capacity of a lake for development without utilizing actual water quality data. In the case of Mendums Pond, however, substantial data exists because of the Clean Lakes Diagnostic/Feasibility Project.

This existing data allows us to verify the results of the model. By utilizing the chlorophyll criteria of 3.0 mg/m^3, which is the average level currently measured in the lake, the model indicates that the existing phosphorus load to the lake of 346 $kgPyr^{-1}$ is significantly lower than the permissible supply of 582 $kgPyr^{-1}$. Table X-10 lists the input data utilized in the model and the phosphorus loading outputs. At this particular lake, additional shoreline property could be developed if best shoreland protection practices were utilized.

Table X-10

PREDICTING THE CAPACITY OF A LAKE FOR DEVELOPMENT*

(version 5.2)

3/17/1992 **software by GLITCH**

CAPACITY FOR DEVELOPMENT ON LAKE: Mendums Pond

Present Development: 120.0 capita-years/yr spent at lake
Chlorophyll-a Criteria: 3.0 mg/m3

Natural Export: 14.08

Residential Export: 0.35

Flushing Rate: 1.43

P Retention Coefficient: 0.79

Recovery(yrs): 0.7-1.2

Permissible Load: 568.3 mg/m2/yr Permissible Supply: 581.8 kg/yr

Natural Supply: 304.3 kg/yr Natural Loading: 297.2 mg/m2/yr

Artificial Supply: 42.0 kg/yr Total Supply: 346.3 kg/yr

Additional allowable cottage units: 673.1 = 168 permanent homes.

*after Dillon & Rigler, 1975